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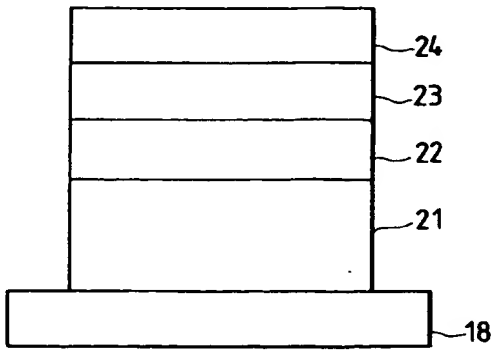
(54) Antireflective film and optical element having the same.

(57) An antireflective film, comprising a film composed of an inorganic compound consisting of Mg, Si, O and F and a film composed of an inorganic compound consisting of Zr, Si and O, shows antireflective property over a wide spectral range even with a limited number of layers. The present invention also provides an optical element comprising a transparent body, a film formed thereon, composed of an inorganic compound consisting of Zr, Si and O and a film formed as an outermost layer facing the air, composed of an inorganic compound consisting of Mg, Si, O and F.

FIG. 9



EP 0 586 050 A1

BACKGROUND OF THE INVENTION

Field of the Inv ntion

The present invention relates to an antireflective film for an optical element adapted for use in a spectacle lens, a camera, optical communication, optical information processing, a binocular, a video still camera, a magnetooptical recording disk, a television or the like.

Related Background Art

In the field of antireflective film for optical elements, there has widely been employed a MgF_2 film having a low refractive index and a low absorption in the visible spectral region. Said MgF_2 film was originally commercialized as an antireflective film formed by vacuum evaporation, for optical elements of glass, and is still used at the present. However, such MgF_2 film formed by vacuum evaporation cannot satisfy the optical and mechanical requirements unless it is heated at a high temperature (200° - 400°C) during and after the evaporation. Consequently, in the preparation of a precision optical element, such MgF_2 film is extremely difficult to prepare, because of thermal deformation or similar reasons. For this reason, there has not been realized a MgF_2 film having sufficient performance for precision optical elements and optical elements made of plastics. Also since it is extremely difficult to reduce the spectral reflectance in a single-layered antireflective MgF_2 film, there is ordinarily employed a multilayered structure having three or more layers.

In addition to the foregoing, there have been proposed an antireflective film principally composed of a complex oxide of Zr and Si and a lens having such antireflective film, as disclosed in the Japanese Patent Laid-open Application Nos. 3-173638 and 3-162943.

Such conventional technologies require a multi-layered antireflective film having three or more layers in order to reduce the reflectance in the spectral reflective characteristics. Such reflective film, if prepared by sputtering or the like, is associated with a low productivity, leading to a high production cost.

SUMMARY OF THE INVENTION

In consideration of the foregoing, the object of the present invention is to provide an excellent antireflective film having an antireflective property in a wide spectral region, with a reduced number of layers.

The present inventor already proposed, in the Japanese Patent Application No. 2-414523, a thin film composed of an inorganic compound consisting of Mg, Si, O and F. Said film has optical and mechanical characteristics at least equivalent to those of the MgF_2 film prepared by vacuum evaporation, does not require a high temperature treatment and can be used also on plastic lenses without any trouble.

Through further investigation, the present inventors have found that an antireflective film exhibiting, even in a two-layered structure, low reflectance characteristics over a wide spectral region comparable to those of the conventional multi-layered antireflective film of three or more layers can be obtained by combining a film, composed of an inorganic compound consisting of Zr, Si and O with the above-mentioned film of the inorganic compound consisting of Mg, Si, O and F, and have reached the present invention.

More specifically, the present invention provides an antireflective film with at least two layers, comprising a film composed of an inorganic compound consisting of Mg, Si, O and F, and a film composed of an inorganic compound consisting of Zr, Si and O, and a transparent optical element provided, at the surface side of said element, with a film composed of an inorganic compound consisting of Zr, Si and O, and, at the outermost layer at the air side, with a film composed of an inorganic compound consisting of Mg, Si, O and F.

In order to improve the stability in time of the optical characteristics of the above-mentioned film composed of an inorganic compound consisting of Mg, Si, O and F, the Si concentration in said inorganic compound is preferably selected within a range of 3 - 20 wt.%. Also the atomic ratios of the constituent elements are preferably selected within following ranges:

$1.3 \leq F/Mg \leq 3.2$

$0.4 \leq O/Mg \leq 1.4$

$0.1 \leq Si/Mg \leq 0.6$

Also, in the above-mentioned film composed of the inorganic compound consisting of Zr, Si and O, the atomic ratios of the constituent elements are preferably selected within following ranges:

$0.5 \leq Si/Zr \leq 15$

$1.6 \leq O/Zr \leq 31.6$

With respect to the atomic ratio of ZrSiO, it was experimentally confirmed that the refractive index of the prepared film varied within a range of about 1.80 to 2.00 by varying the Si content within a range of 5 to 15 wt.%. Fig. 15 shows the change in the refractive index of ZrSiO film as a function of Si content. Also Michael A. Russak and Christopher V. Jahnes already reported, in Journal of Vacuum Science & Technology, A7(3), May/Jun 1989, that said film assumed an amorphous structure with a SiO_2 content of 10 at.% and that said film was superior in thermal and mechanical properties than pure zirconia film. For these reasons, it is anticipated that said film can be easily controlled, in the production, to an optically stable high refractive index, particularly in a range of about 1.88 to 1.96. Furthermore, A. Feldman, E. N. Farabaugh and W. K. Haller reported, in Journal of Vacuum Science & Technology, A4(6), Nov/Dec 2969-2974, 1986, the excellent optical and mechanical properties of amorphous ZrSiO film. On the other hand, the materials frequently employed in the optical thin films show significant fluctuation in the refractive index and are extremely difficult to handle in the above-mentioned range of refractive index (1.88 - 1.96). Based on these facts, the present inventor decided to use said ZrSiO film as a part of the multi-layered film of the present invention, anticipating that the above-mentioned drawbacks could be resolved.

Said films can be prepared by reacting the constituent elements or compounds containing said elements in plasma, or more specifically by sputtering. The sputtering conditions are suitably determined according to the desired optical characteristics, but MgF_2 and Si can be employed as targets for sputtering for forming the film composed of an inorganic compound consisting of Mg, Si, O and F (said film being hereinafter represented as MgSiOF film regardless of the atomic ratio thereof), and ZrO_2 and Si can be employed as targets for sputtering for forming the film composed of an inorganic compound consisting of Zr, Si and O (said film being hereinafter represented as ZrSiO film regardless of the atomic ratio thereof). There are preferably employed Ar and O_2 as the sputtering gas, with a background pressure of about 1.1×10^{-3} Pa and a sputtering gas pressure of about 6×10^{-1} Pa.

The antireflective film of the present invention comprises, on a substrate consisting of a transparent optical element such as a glass lens or a plastic lens for use in spectacles or a camera, a ZrSiO film formed on the side of the surface of said substrate, and a MgSiOF film formed thereon as an outermost layer at the air side. At least these two layers can provide an antireflective film for a wide spectral region, but the number of layers may be made larger. Also the substrate may be provided, in advance, with an organic hard coating.

The MgSiOF film employed in the present invention is featured by a change in the molecular refraction, presumably due to a change in the Si-O-Si bonding angle or in the Si-Si atomic distance, resulting from the bonding of at least Si and F. In the aforementioned Japanese Patent Application No. 2-414523, it is described that the low refractive index of the MgSiOF film is ascribable to said change in the molecular refraction. Said MgSiOF film, being preparable without heating of the substrate, is at least comparable or superior, in mechanical properties (scratch resistance, adhesion strength etc.) and in optical properties (transmittance, stability of refractive index, absorption etc.) to the conventional, MgF_2 film prepared by vacuum evaporation with heating of the substrate to a high temperature. The applicability of said MgSiOF film to the plastic substrate, which does not withstand the high temperature treatment, is an extremely important feature. The reason for the low refractive index of the MgSiOF film will be explained further in the following, though it is still an assumed theory.

The reduced refractive index of the MgSiOF film is presumably ascribable to a change in the molecular refraction of the inorganic compound constituting said film. More specifically, the positive Si^{4+} ion has a fixed ion reflaction, but the ion refraction of O^{2-} ion varies depending on the bonding state thereof. This signifies that Si^{4+}, having a small ion radius, has a strong effect of polarizing the adjacent O^{2-} ion. Also in the reaction between Si and F in the plasma, there will result stabilization caused by a charge displacement between $Si^{\delta+}$ and radical F atom (radical F atom being stabilized by accepting an electron, because of its strong electronegativity), thus generating a product represented by $Si^{\delta+}$-$F^{\delta-}$. As a result, the Si-Si bond is bent by a polarization caused by the F atom, with a variation in the Si-Si distance. Consequently there results a change in the Si-O-Si bonding angle, leading to a variation in the molecular refraction.

The Si-Si bonding distance can be determined from the following equation (1):

$$d_{Si-Si} = 2r_0 \sin(\theta/2) \quad (1)$$

wherein:

r_0: Si-O bonding distance (1.60 Å)

θ: Si-O-Si bonding angle

said bonding angle θ can be obtained from the following equation (2):

$$\theta = 2\sin^{-1}\left[\left(\frac{\omega_s^2 M}{\alpha} - 1\right)\frac{m}{2M}\right]^{1/2} \qquad (2)$$

wherein:

ω_s: wave number of elongation-contraction mode (cm^{-1})
M: atomic mass (Si)
m: atomic mass (O)
α: central force constant (460 Nm^{-1}).

Based on ω_s of 1066 cm^{-1} obtained from an infrared absorption spectrum shown in Fig. 17, θ is determined as 137.6°, and this value is substituted in the equation (1) to obtain d_{Si-Si} = 2.98.

These values indicate, in comparison with a SiO_x film formed by sputtering with a Si target and a mixture of Ar and O_2 (d_{Si-Si} = 3.04 Å, θ = 144°), that the Si-Si distance becomes shorter and the Si-O-Si bonding angle becomes smaller.

These results are presumably based on the polarizing effect of F atoms. Also based on the infrared absorption spectrum of the above-mentioned SiO_x film (target: Si, sputtering gas: Ar + O_2), the value x of SiO_x at the wave number 1068 cm^{-1} is determined as 1.72. Since the refractive index of $SiO_{1.72}$ is about 1.5, the low refractive index of the MgSiOF film of the present invention is significantly related with the polarizing effect of Si-F bond on the Si-Si and Si-O-Si bonds.

As explained in the foregoing, in the present invention, the refractive index can be lowered by a variation in the molecular refraction (by a reduction in the bonding angle). It is therefore rendered possible to suppress the change in the molecular volume, caused by oxygen ions in the course of sputtering, thereby avoiding a high refractive index as in the film formed by IAD process (refractive index becoming higher if the molecular volume increases by oxygen ion taking in), and to obtain a refractive index comparable to that of the MgF_2 film.

In the following there will be explained the stability in time of the optical characteristics of the MgSiOF film of the present invention. In case it is necessary to maintain the refractive index at a low constant value in the use of the MgSiOF film in the antireflective film or the like, the variation of the refractive index in time can be suppressed by the adjsutment of the Si concentration in the film.

According to the investigation of the present inventor, of which results will be explained in more details in the embodiments, a low Si concentration in the film reduces the proportion of SiO_x and increases the proportion of Si-F_2 bonds, in comparison with the case of an excessively high Si concentration. More specifically, a Si concentration of 3 to 10 wt.% improves the stability in time of the refractive index. This is presumably due to a fact that a low Si concentration stimulates the Si-F bonding of a higher bonding energy.

Also the experiments of the present inventor confirmed that, even in a region of the Si concentration exceeding 10 wt.%, the refractive index of the MgSiOF film gradually increased until the Si content reached 15 wt.%, and remained almost constant within a region of Si content of 15 to 20 wt.%, as shown in Fig. 13.

Also the present inventor investigated the variation of the refractive index in time, in a MgSiOF film of a Si concentration of 5 wt.% and that of a Si concentration of 20 wt.%. The obtained results are shown in Fig. 14, in which white circles stand for the case of Si concentration of 20 wt.%, and black circles stand for the case of Si concentration of 5 wt.%. It will be understood that said variation in time is small in either case.

Based on these experimental results, it can be judged that a MgSiOF film with Si concentration in a range of 5 to 20 wt.% is adapted for use in the antireflective film.

A two-layered antireflective film of a wide spectral region can be obtained by forming the above-mentioned MgSiOF film of a low refractive index as the outermost layer at the air side, and forming a ZrSiO film at the side contacting the surface of an optical element constituting the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view of a sputtering apparatus employed in forming the MgSiOF film;
Fig. 2 is a schematic view showing a variation of the sputtering apparatus employed in forming the MgSiOF film;
Fig. 3 is a chart showing an infrared absorption spectrum of the MgSiOF film;
Fig. 4 is a chart showing the result of measurement of Knoop hardness of a MgSiOF film and an evaporated MgF_2 film;

Fig. 5 is a chart showing the result of measurement of adhesion strength of a MgF_2 film;
Fig. 6 is a chart showing the result of measurement of adhesion strength of a MgSiOF film;
Fig. 7 is a chart showing spectral transmittance of a MgSiOF film and an evaporated MgF_2 film;
Fig. 8 is a schematic view of a sputtering apparatus employed in an embodiment of the present invention;
Fig. 9 is a view showing the structure of an antireflective film formed in the embodiment 1 of the present invention;
Fig. 10 is a chart showing the spectral reflectance of the antireflective film formed in the embodiment 1 of the present invention;
Fig. 11 is a view showing the structure of an antireflective film formed in the embodiment 2 of the present invention;
Fig. 12 is a chart showing the spectral reflectance of the antireflective film formed in the embodiment 2 of the present invention;
Fig. 13 is a chart showing the relationship between the Si content in the film and the refractive index thereof;
Fig. 14 is a chart showing the time-dependent variation of the refractive index of the film;
Fig. 15 is a chart showing the relationship between the Si content in the film and the refractive index thereof;
Fig. 16 is a chart showing the relationship among the refractive index of the film, the sputtering gas pressure and the RF power; and
Fig. 17 is a chart showing the infrared absorption spectrum of the film.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Prior to the description of the embodiments of the antireflective film of the present invention, there will be shown experimental examples for investigating the performance of the MgSiOF film.

Experimental Examples

Fig. 1 is a schematic view of a sputtering apparatus Model SPF-530H, supplied by Nichiden Anelva Co., Ltd. and employed for forming a MgSiOF film.

In said apparatus, on a MgF_2 target (6") 1, there was placed a Si wafer (3") 2. Into a vacuum chamber 3 there were introduced argon 4 and oxygen 5 at respective flow rates of 40 sccm and 20 sccm, and the evacuating rate of a cryopump 7 was regulated by with a variable orifice 6 in such a manner as to obtain a pressure of 6×10^{-1} Pa in the vacuum chamber. The background pressure prior to said gas introduction was 1.1×10^{-3} Pa. A high frequency power of 500 W was applied to the MgF_2 target, thereby depositing a MgSiOF film on a substrate 8, which was not heated during the sputtering operation.

Thus obtained MgSiOF film showed sufficient optical characteristics of a refractive index n = 1.40 - 1.41 and an absorption coefficient $\alpha = 2 - 3 \times 10^5$ m^{-1} (at λ = 400 nm) for use as a film on an optical element.

Fig. 2 is a schematic view of a variation of the above-mentioned sputtering apparatus. In this embodiment, the MgF_2 target 1 and the Si target 2 are placed on separate holders, and an RF power source is connected to the MgF_2 target 1 while a DC power source is connected to the Si target 2. Thus a MgSiOF film was prepared, under the same conditions as explained above, by applying RF and DC voltages respectively to said MgF_2 target 1 and Si target 2.

Thus obtained MgSiOF film showed sufficient optical characteristics of a refractive index of 1.40 - 1.41 and an absorption coefficient of $2 - 3 \times 10^5$ m^{-1} (at λ = 400 nm) for use as a film for an optical element.

Also films were prepared on borosilicate crown glass substrates, in a sputtering apparatus same as shown in Fig. 1, employing a mixed target of MgF_2 and Si (20 wt.%) and Ar and O_2 as sputtering gas under varied conditions. The distance between the substrate and the target was maintained constant at 116 mm. The sputtering conditions and the optical characteristics of the obtained film are shown in Table 1.

Fig. 16 shows the relationship among the refractive index of the film, the sputtering gas pressure and the RF power, in case the sputtering gas pressure was varied while the O_2 flow rate was maintained constant at 40 sccm in the mixture of Ar and O_2. Although Ar gas flow rate was also varied at the same time, said variation little affected the refractive index of the film. On the other hand, when the O_2 gas flow rate was varied while the Ar gas flow rate was maintained constant at 40 sccm, a lowest refractive index close to 1.40 was obtained when the flow rate ratio O_2/Ar was 1/16.

Table 1

Background pressure (Pa)	Sputtering pressure (Pa)	Gas flow rate (sccm) Ar	O_2	N_2	RF power (W)	Rate (Å/sec)	Film thickness (Å)	Refractive index of film Nf	Absorption coefficient $\alpha(m^{-1})$
1.1×10^{-3}	6.0×10^{-1}	40	20		500	0.15	832	1.4119	1.5×10^{5}
1.1×10^{-3}	6.0×10^{-1}	40	20		500	0.16	982	1.4257	2.2×10^{5}
1.1×10^{-3}	6.0×10^{-1}	40	20		500	0.15	911	1.4265	1.8×10^{5}
1.1×10^{-3}	6.0×10^{-1}	40	2.5		500	0.17	917	1.4169	2.3×10^{5}
1.1×10^{-3}	1.1	40	2.5		500	0.14	1457	1.4072	2.8×10^{5}
1.1×10^{-3}	1.1	40	2.5		500	0.12	778	1.4137	1.8×10^{5}
9.3×10^{-4}	1.1	40	2.5		500	0.13	868	1.4117	2.0×10^{5}
1.1×10^{-3}	1.1	40	2.5		500	0.16	1084	1.4065	2.4×10^{5}
1.1×10^{-3}	1.1	40	2.5		500	0.12	797	1.4122	1.8×10^{5}
1.1×10^{-3}	1.1	40	2.5		500	0.13	1173	1.4066	2.6×10^{5}
1.1×10^{-3}	1.1	40	2.5		700	0.21	829	1.4018	1.8×10^{5}
1.1×10^{-3}	4.0	40	2.5		700	0.097	1405	1.4101	2.3×10^{5}
1.1×10^{-3}	1.1	40	2.5		1000	0.32	923	1.4090	1.5×10^{5}

EP 0 586 050 A1

Table 1 (continued)

Background pressure (Pa)	Sputtering pressure (Pa)	Gas flow rate (sccm) Ar	O_2	N_2	RF power (W)	Rate (Å/sec)	Film thickness (Å)	Refractive index of film Nf	Absorption coefficient $\alpha(m^{-1})$
1.1×10^{-3}	1.1	40	2.5		700	0.20	927	1.4020	1.9×10^5
1.1×10^{-3}	1.1	40	2.5	10	700	0.15	695	1.4035	1.8×10^5

Then there will be explained the result of analysis of the infrared absorption spectrum of the MgSiOF film. As shown in Fig. 3, the MgSiOF film of the present invention was confirmed to contain a Si-F_2 bond indicated by peaks at 920 and 832 cm^{-1}, and a Si-F bond indicated by a peak at 850 cm^{-1}.

The spectrum shown in Fig. 3 clearly indicates the presence of a Si-F bond with a high bonding energy in the MgSiOF film, and this result indicates that the MgSiOF film is a compound film.

In the following there is shown the result of investigation of the mechanical properties of the MgSiOF film. Samples of a MgF_2 film formed by evaporation with a substrate temperature of 270 °C, a MgF_2 film formed by evaporation with the substrate at the room temperature, and a MgSiOF film of the present invention formed by sputtering were prepared on borosilicate crown glass substrates. The adhesion strength was tested by peeling with a cellophane adhesive tape at 4 - 5 kg/cm^2. The solvent resistance was tested by wiping the film strongly about fifteen times with lens cleaning paper impregnated with acetone. The scratch resistance was tested by rubbing the film with steel wool of #0000 under a load of 800 g, for 50 reciprocating strokes within 30 seconds. The obtained results are summarized in Table 2.

Table 2

	Tape test	Solvent resistance	Scratch resistance
Borosilicate crown glass/evaporated MgF_2 (substrate heated at 270 °C)	OK	OK	OK
Borosilicate crown glass/evaporated MgF_2 (room temp.)	NO	NO	NO
Borosilicate crown glass/sputtered MgSiOF	OK	OK	OK

Fig. 4 shows the comparison of Knoop hardness of the sputtered MgSiOF film (prepared at room temp.) and the evaporated MgF_2 film (prepared at 270 °C). The Knoop hardness was measured with a Micro Vickers Hardness Tester MVK-G3500AT manufactured by Akashi Mfg. Co., with loads of 10, 15 and 25 g. Both samples were prepared on borosilicate crown glass substrates. Results of measurements of a borosilicate crown glass plate only and a fused quartz plate are also shown for reference. The results shown in Fig. 4 indicate that the Knoop hardness of the MgSiOF film of the present invention is higher than that of the evaporated MgF_2 film (prepared at 270 °C) and is comparable to that of the fused quartz plate.

Also the adhesion strengths of the sputtered MgSiOF film (prepared at room temperature) and the evaporated MgF_2 film (prepared at 270 °C) are respectively shown in Figs. 6 and 5. Both samples were prepared on borosilicate crown glass substrates, and the adhesion strength was measured with the Scratch Tester SST-101 manufactured by Shimadzu Mfg. Co. The measurement was conducted under conditions of a scratching speed of 10 μm/sec., a cartridge amplitude of 100 μm, a maximum load of 50 gf, and a load rate of 2 μm/sec.

As shown in Fig. 6, the MgSiOF film was not peeled up to a load of 40 gf. On the other hand, as shown in Fig. 5, the evaporated MgF_2 film started to break at 10 gf and was completed peeled at 24 gf.

These results indicate that the MgSiOF film is significantly superior, in mechanical strength, to the conventional evaporated MgF_2 film.

Fig. 7 shows the spectral transmittance of the sputtered MgSiOF film (prepared at room temperature) and the evaporated MgF_2 film (prepared at 270 °C) deposited on one side of the substrate, which consisted of borosilicate crown glass in both samples. Fig. 7 indicates that the MgSiOF film has optical performance comparable to that of the MgF_2 film conventionally used as the antireflective film, and has a transmittance of about 94 % in the visible wavelength region.

In the experimental examples mentioned above, the MgSiOF film was prepared by sputtering, but it can also be prepared by other plasma-based film forming methods such as ion plating. Also in the foregoing examples, there was employed a MgF_2 target in which small pieces of Si were mixed, but there may also be employed separate targets of MgF_2 and Si in reactive sputtering.

[Embodiment 1]

Fig. 8 shows an in-line sputtering apparatus ILC-3123 manufactured by Nichiden Anelva Co., Ltd. In a sputtering chamber 11, there were placed a mixed target 12 consisting of ZrO_2 and Si (15 wt.%), and a mixed target 13 consisting of MgF_2 and Si (20 wt.%), and a three-layered film was prepared by sputtering. The substrate consisted of a plastic lens (a high refractive urethane resin lens; n = 1.60) 18 with an organic hard coating 21.

The plastic lens 18 was washed in a 7-tank ultrasonic washer as the surface treatment prior to the sputtering, then set on a substrate holder 15, with the convex surface downward, and was placed in a load lock chamber 14 of the sputtering apparatus. Then said plastic lens 18 was transferred to th sputtering chamber 11, which was subsequently evacuated to a background pressure of 1.1×10^{-3} Pa. Then argon and oxygen were introduced, respectively at flow rates of 40 and 20 sccm, by mass flow controllers 16, 17, to attain a pressure of 6.0×10^{-1} Pa in the sputtering chamber 11. Then an RF power of 700 W was applied

to effect sputtering with the mixed target 13, consisting of ZrO_2 and Si (15 wt.%), thereby forming a ZrSiO film 22 of a geometrical thickness of 589 Å (optical thickness nd = λ/4, λ = 450 nm, n = 1.91) subsequently the oxygen flow rate alone was changed to 2.5 sccm while the sputtering pressure of argon and oxygen was maintained at 6.0 x 10^{-1} Pa and the RF power was also maintained at 700 W as in the foregoing case. In this manner there was formed a second ZrSiO film 23 of a geometrical thickness of 574 Å (nd = λ/4, λ = 450 nm, n = 1.96). Subsequently the evacuating speed of the cryopump 20 was reduced by the variable orifice 19 to regulate the pressure of argon and oxygen at the sputtering to 1.1 Pa. Thus a MgSiOF film 24, of a geometrical thickness of 792 Å (nd = λ/4, λ = 450 nm, n = 1.42), constituting a third layer, was formed under the conditions same as those for the second layer. Thus the antireflective film on the convex face of the plastic lens 18 is completed. Then the plastic lens 18 is transferred to a load lock chamber 14, taken out therefrom, then set on the holder 15 with the concave side downwards, and introduced again into said load lock chamber 14. The steps thereafter are similar to those for film formation on the convex face. In this manner the multi-layered antireflective film is formed on both faces of the plastic lens. The structure and the spectral reflectance of said antireflective film are respectively shown in Figs. 9 and 10. Table 3 shows the result of mechanical performance, evaluated in the following manner, of thus obtained sputtered antireflective film:

scratch resistance: by rubbing with steel wool of #0000 under a load of 800 g, for 50 reciprocating strokes within 30 seconds;

adhesion strength: by peeling with a cellophane adhesive tape with a force of 4 - 5 kg/cm^2;

heat resistance: 2 minutes standing at 100 °C.

Table 3

Scratch resistance	Adhesion resistance	Heat resistance
slight scars	no film peeling	satisfactory

[Embodiment 2]

Fig. 11 illustrates an example of the optical element bearing the antireflective film of the present invention. After a spectacle glass (flint glass n_d = 1.60) 25 was subjected to ultrasonic washing, it was set on a jig and placed in the chamber of an RF sputtering apparatus shown in Fig. 8. After the chamber was evacuated to a pressure of 1 x 10^{-3} Pa, argon and oxygen were introduced with respective flow rates of 40 and 20 sccm to a pressure of 6.0 x 10^{-1} Pa, and sputtering was conducted with a mixed target of ZrO_2 and Si to form a ZrSiO film 26, constituting a first layer, with an optical thickness of 0.50 λ (λ = 510 nm, n = 1.92). Then argon and oxygen were introduced into the chamber with respective flow rates of 40 and 2.5 sccm to a pressure of 1.1 Pa, and sputtering was conducted with a mixed target of MgF_2 and Si to form a MgSiOF film 27, constituting a second layer, with an optical thickness of 0.25λ (λ = 510 nm, n = 1.41). The spectral reflectance of thus obtained antireflective film is shown in Fig. 12. As will be apparent from Fig. 12, the antireflective film of the present embodiment shows a low reflectance over a wide spectral range comparable to that of the conventional antireflective film of three or more layers.

As explained in the foregoing, the present invention provides an antireflective film of a wide spectral range which has not been attained by a two-layered structure, by the combination of a MgSiOF film and a ZrSiO film, and therefore enables production of an inexpensive, practical antireflective film with a satisfactory productivity, and of an optical element provided with said antireflective film.

Besides the MgSiOF film constituting the outermost layer at the air side, having a tight crystal structure and a mechanical strength superior to that of the conventional films for the optical element, is excellent in durability and shock resistance. Also as the deposited dusts can be easily removed, there can be dispensed with the water-repellent organic coating which has been employed in the plastic spectacle lenses.

Claims

1. An antireflective film comprising:
   a film composed of an inorganic compound consisting of Mg, Si, O and F; and
   a film composed of an inorganic compound consisting of Zr, Si and O.

2. An antireflective film according to claim 1, wherein the film composed of an inorganic compound consisting of Mg, Si, O and F has the atomic ratios of the constituent elements in the following ranges:
   $1.3 \leq F/Mg \leq 3.2$;
   $0.4 \leq O/Mg \leq 1.4$;
   $0.1 \leq Si/Mg \leq 0.6$.

3. An antireflective film according to claim 1, wherein the film composed of an inorganic compound consisting of Zr, Si and O has the atomic ratios of the constituent elements in the following ranges:
   $0.5 \leq Si/Zr \leq 15$;
   $1.6 \leq O/Zr \leq 31.6$.

4. An optical element comprising:
   a transparent body;
   a film formed thereon, composed of an inorganic compound consisting of Zr, Si and O; and
   a film formed as an outermost layer facing the air, composed of an inorganic compound consisting of Mg, Si, O and F.

5. An optical element according to claim 4, wherein the film composed of an inorganic compound consisting of Mg, Si, O and F has the atomic ratios of the constituent elements in the following ranges:
   $1.3 \leq F/Mg \leq 3.2$;
   $0.4 \leq O/Mg \leq 1.4$;
   $0.1 \leq Si/Mg \leq 0.6$

6. An optical element according to claim 4, wherein the film composed of an inorganic compound consisting of Zr, Si and O has the atomic ratios of the constituent elements in the following ranges:
   $0.5 \leq Si/Zr \leq 15$;
   $1.6 \leq O/Zr \leq 31.6$.

7. A method of preparing an antireflective film as claimed in any one of claims 1 to 3, the method comprising reacting the constituent elements in plasma.

8. A method as claimed in claim 7, wherein the film is prepared by sputtering.

FIG. 1

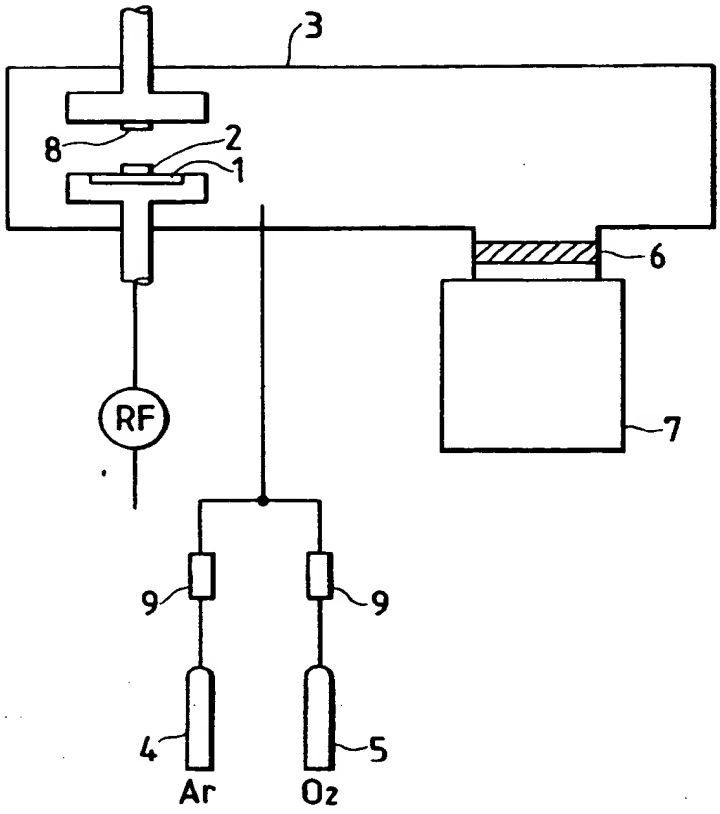


FIG. 2

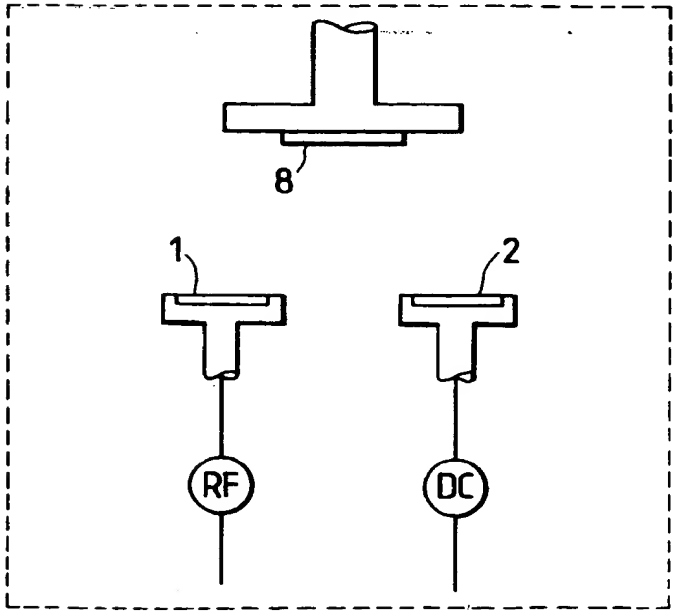


FIG. 3

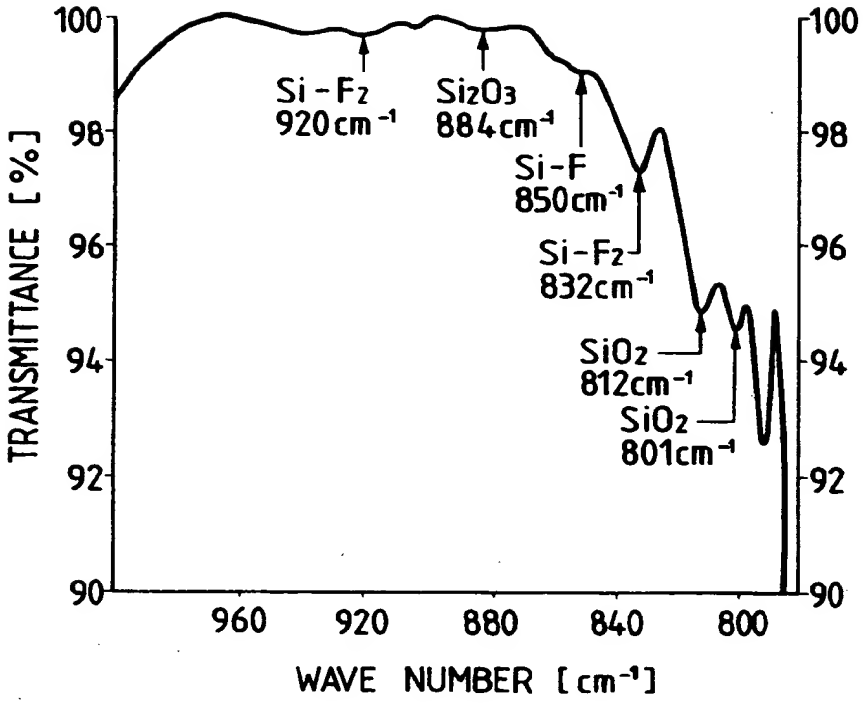

100
98
96
94
92
90
TRANSMITTANCE [%]
Si-F2
920cm-1
Si2O3
884cm-1
Si-F
850cm-1
Si-F2
832cm-1
SiO2
812cm-1
SiO2
801cm-1
960
920
880
840
800
WAVE NUMBER [cm-1]

FIG. 4

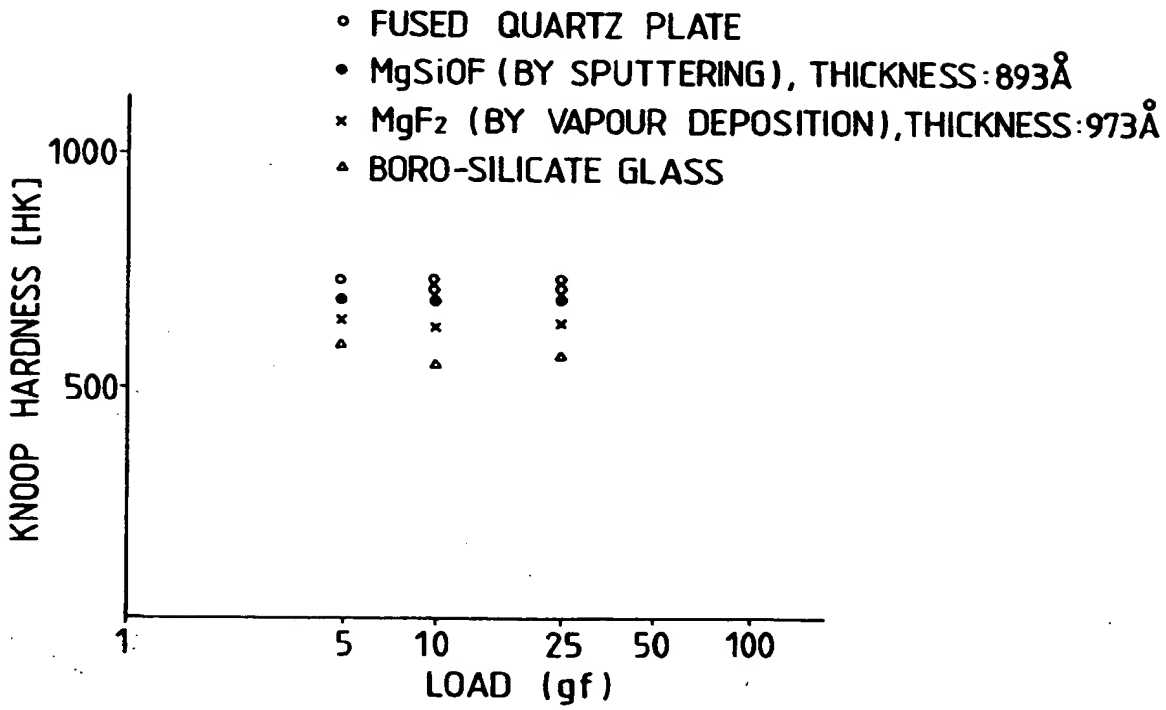

° FUSED QUARTZ PLATE
• MgSiOF (BY SPUTTERING), THICKNESS: 893Å
× MgF2 (BY VAPOUR DEPOSITION), THICKNESS: 973Å
▵ BORO-SILICATE GLASS
1000
500
KNOOP HARDNESS [HK]
1
5
10
25
50
100
LOAD (gf)

FIG. 6

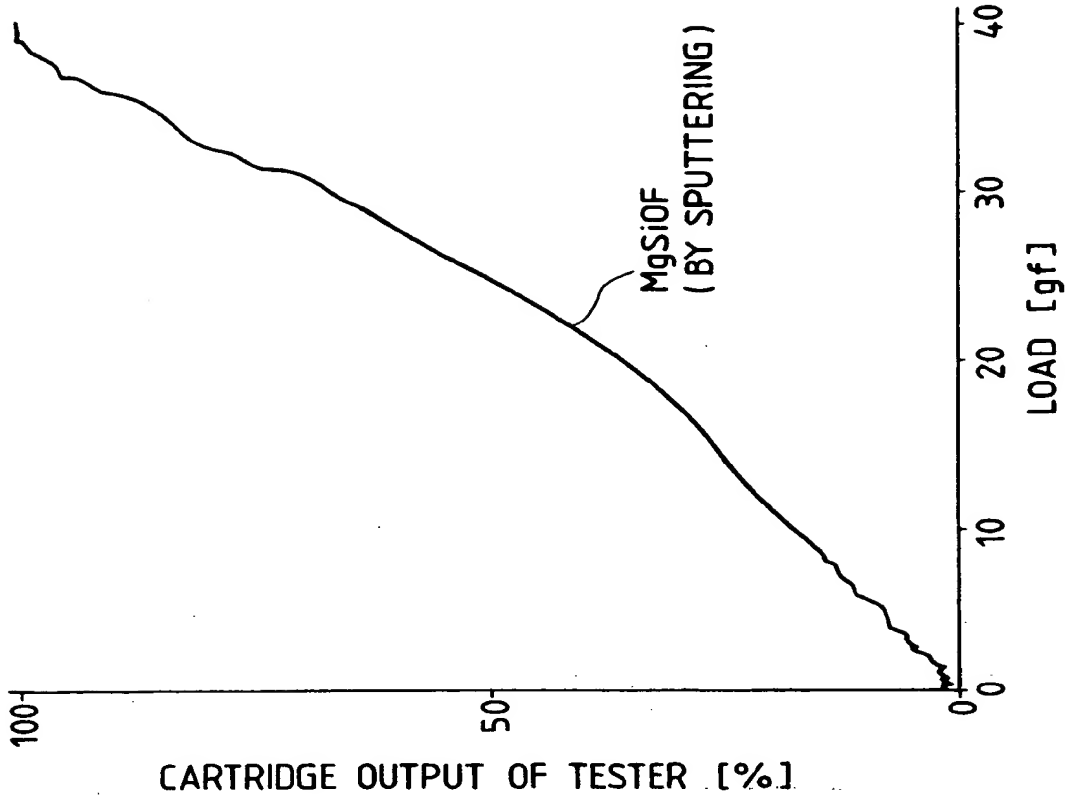

MgSiOF
(BY SPUTTERING)
LOAD [gf]
0
10
20
30
40
100
50
0
CARTRIDGE OUTPUT OF TESTER [%]

FIG. 5

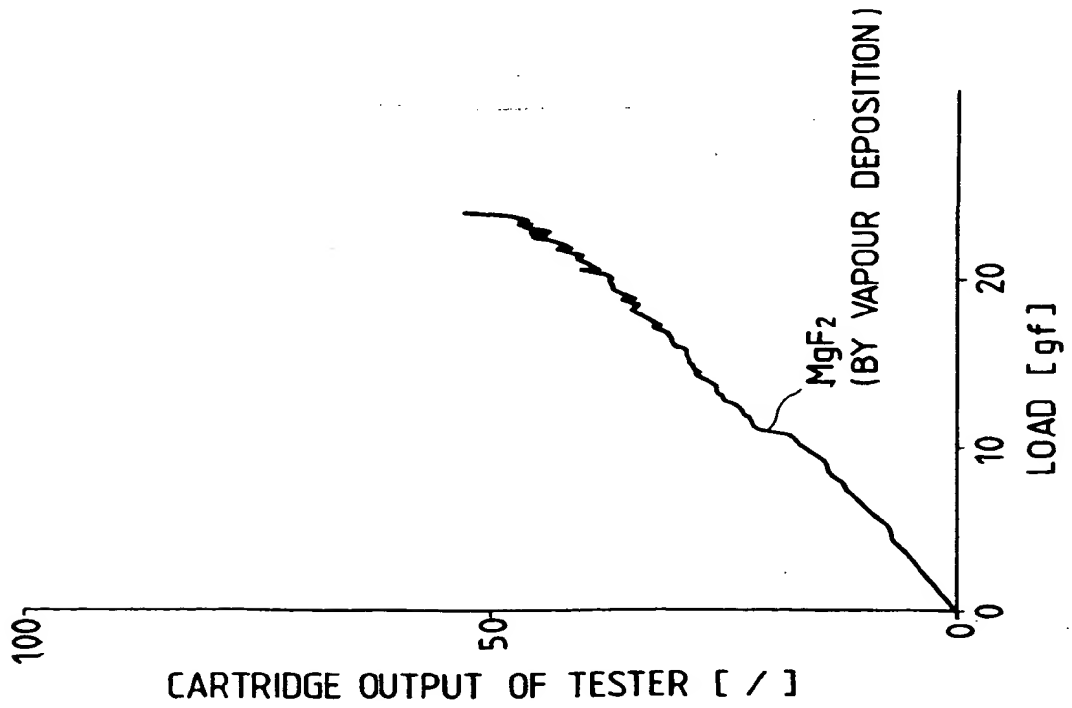

MgF_2
(BY VAPOUR DEPOSITION)
LOAD [gf]
0
10
20
100
50
0
CARTRIDGE OUTPUT OF TESTER [/]

FIG. 7

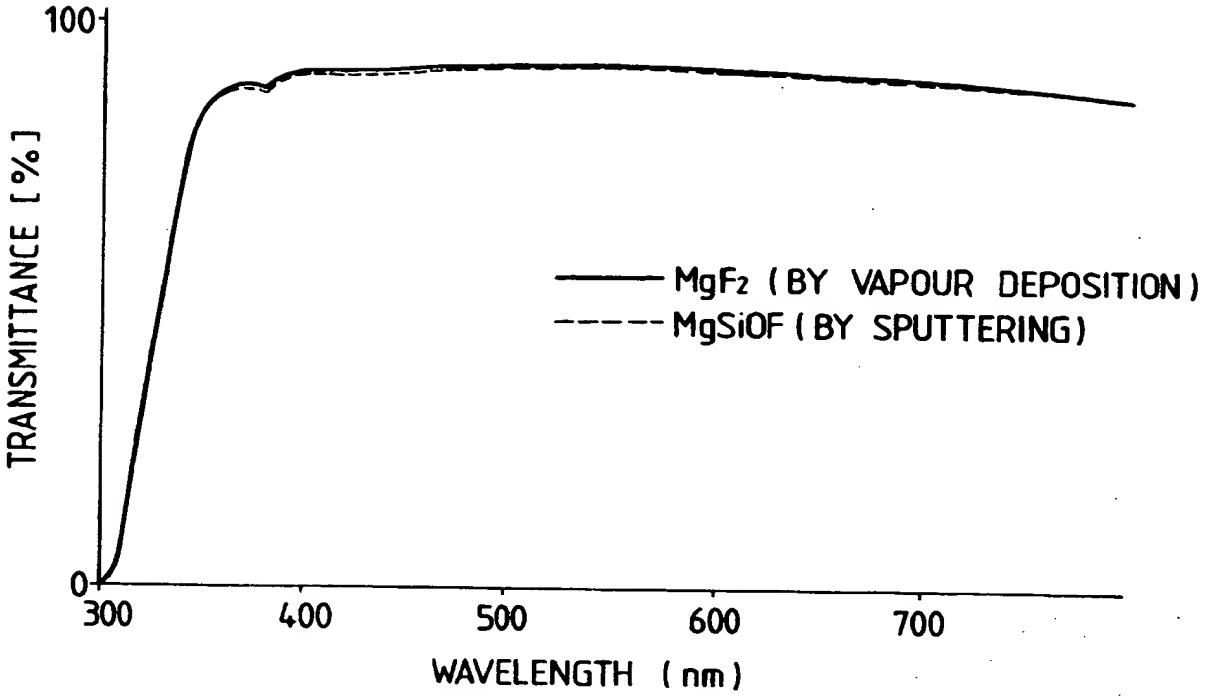

100
0
TRANSMITTANCE [%]
300
400
500
600
700
WAVELENGTH (nm)
MgF2 (BY VAPOUR DEPOSITION)
MgSiOF (BY SPUTTERING)

FIG. 8

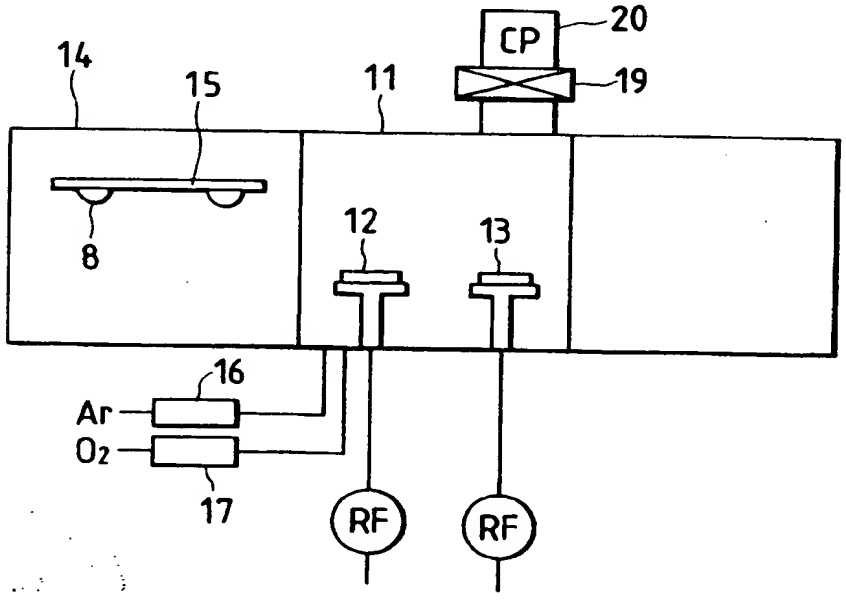

CP
20
19
14
15
11
8
12
13
16
Ar
O2
17
RF
RF

FIG. 9

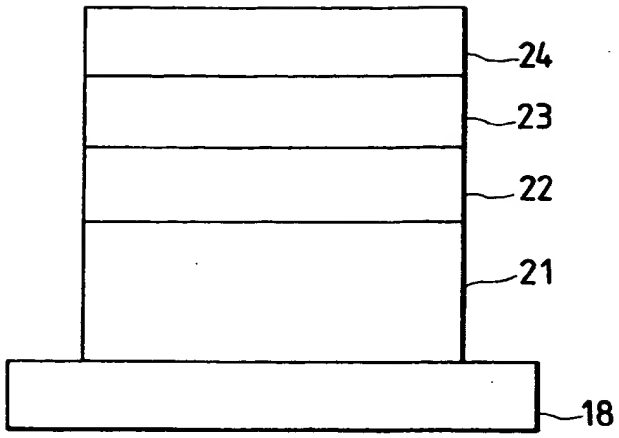

24
23
22
21
18

FIG. 10

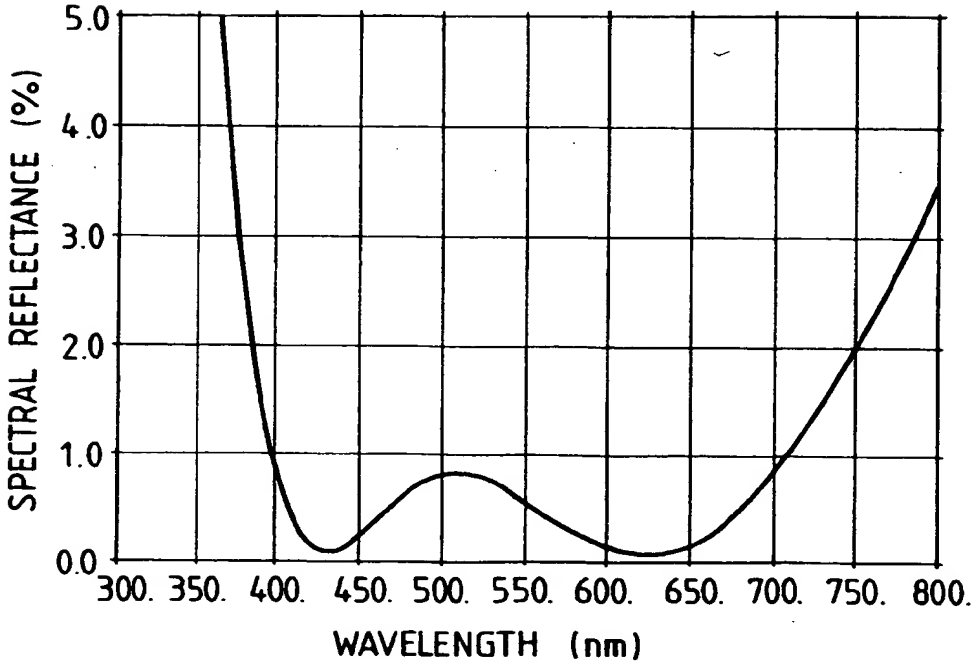

5.0
4.0
3.0
2.0
1.0
0.0
SPECTRAL REFLECTANCE (%)
300. 350. 400. 450. 500. 550. 600. 650. 700. 750. 800.
WAVELENGTH (nm)

FIG. 11

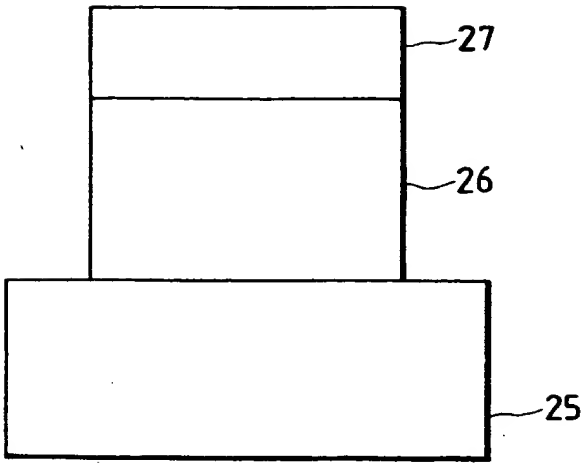

27
26
25

FIG. 12

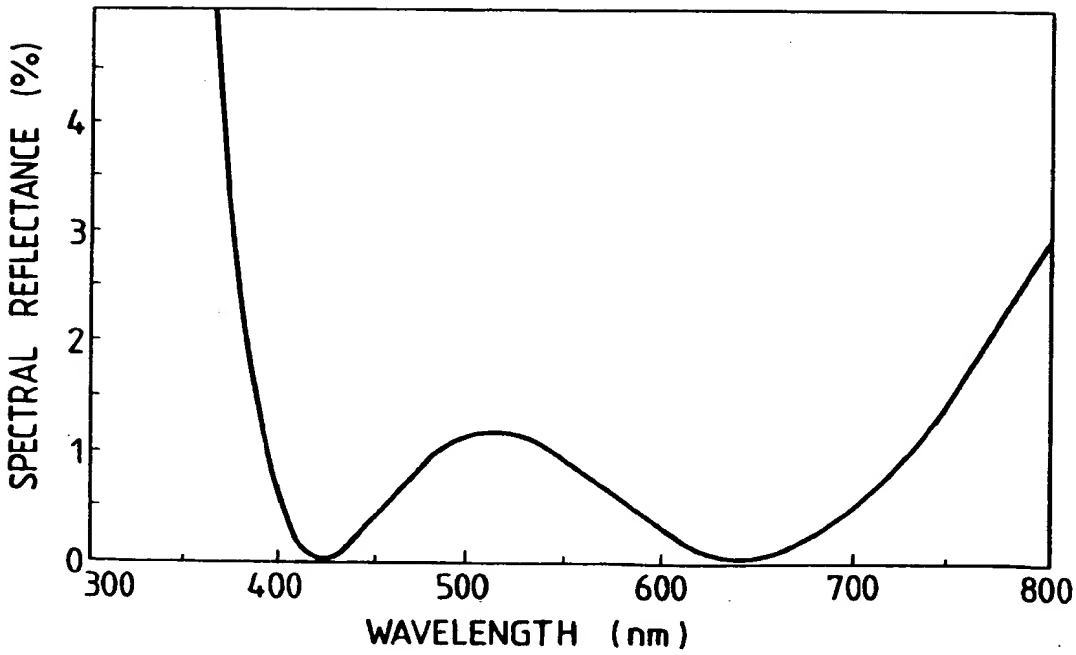

SPECTRAL REFLECTANCE (%)
0
1
2
3
4
300
400
500
600
700
800
WAVELENGTH (nm)

FIG. 13

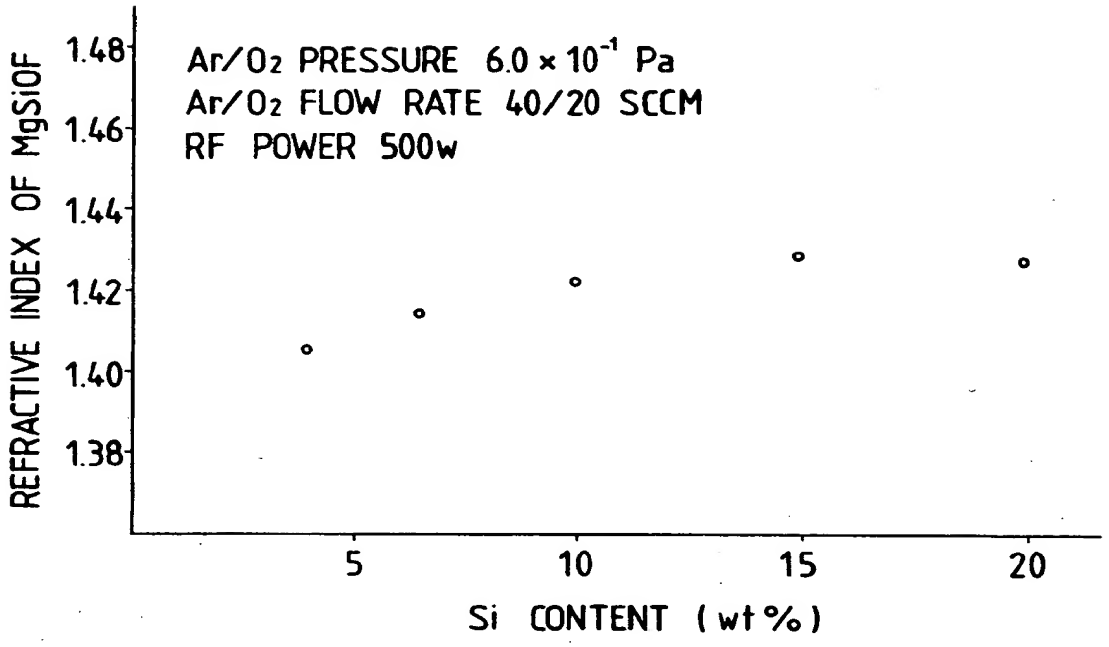

Ar/O2 PRESSURE 6.0 × 10-1 Pa
Ar/O2 FLOW RATE 40/20 SCCM
RF POWER 500w
REFRACTIVE INDEX OF MgSiOF
1.48
1.46
1.44
1.42
1.40
1.38
5
10
15
20
Si CONTENT (wt%)

FIG. 14

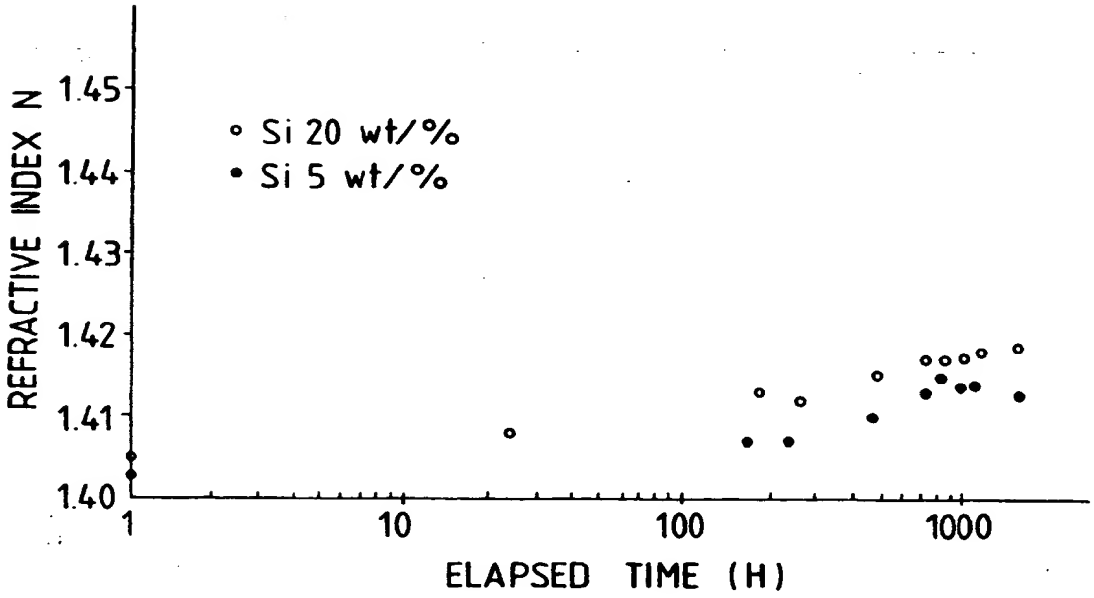

° Si 20 wt/%
• Si 5 wt/%
REFRACTIVE INDEX N
1.45
1.44
1.43
1.42
1.41
1.40
1
10
100
1000
ELAPSED TIME (H)

FIG. 15

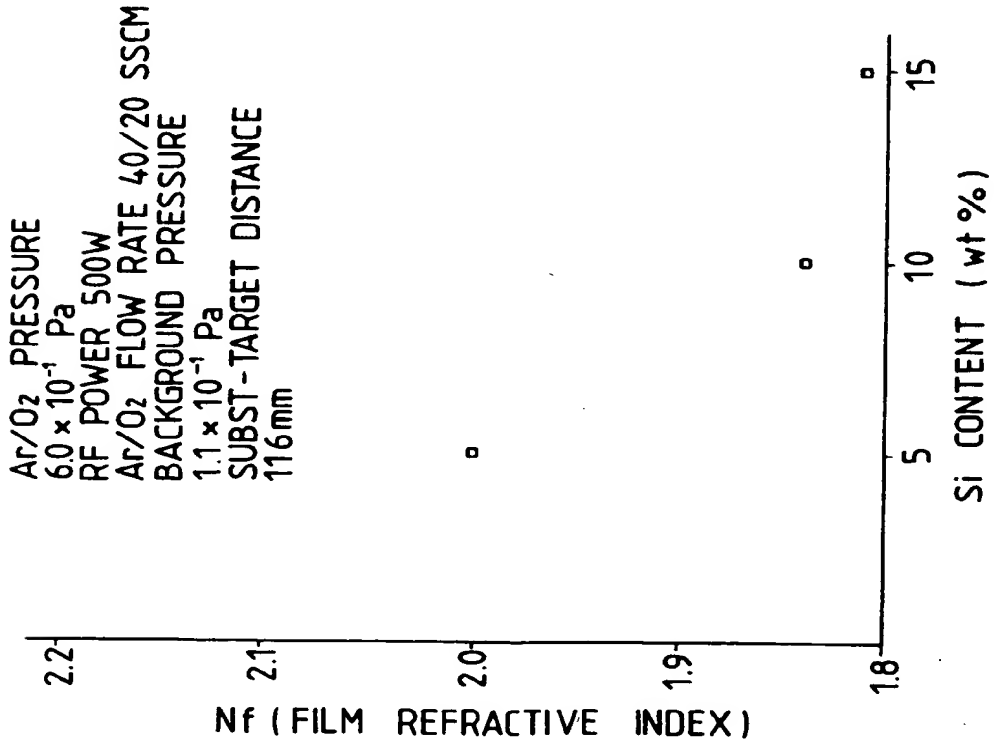

Ar/O2 PRESSURE
6.0 x 10-1 Pa
RF POWER 500W
Ar/O2 FLOW RATE 40/20 SSCM
BACKGROUND PRESSURE
1.1 x 10-1 Pa
SUBST-TARGET DISTANCE
116mm
2.2
2.1
2.0
1.9
1.8
Nf (FILM REFRACTIVE INDEX)
5
10
15
Si CONTENT (wt %)

FIG. 16

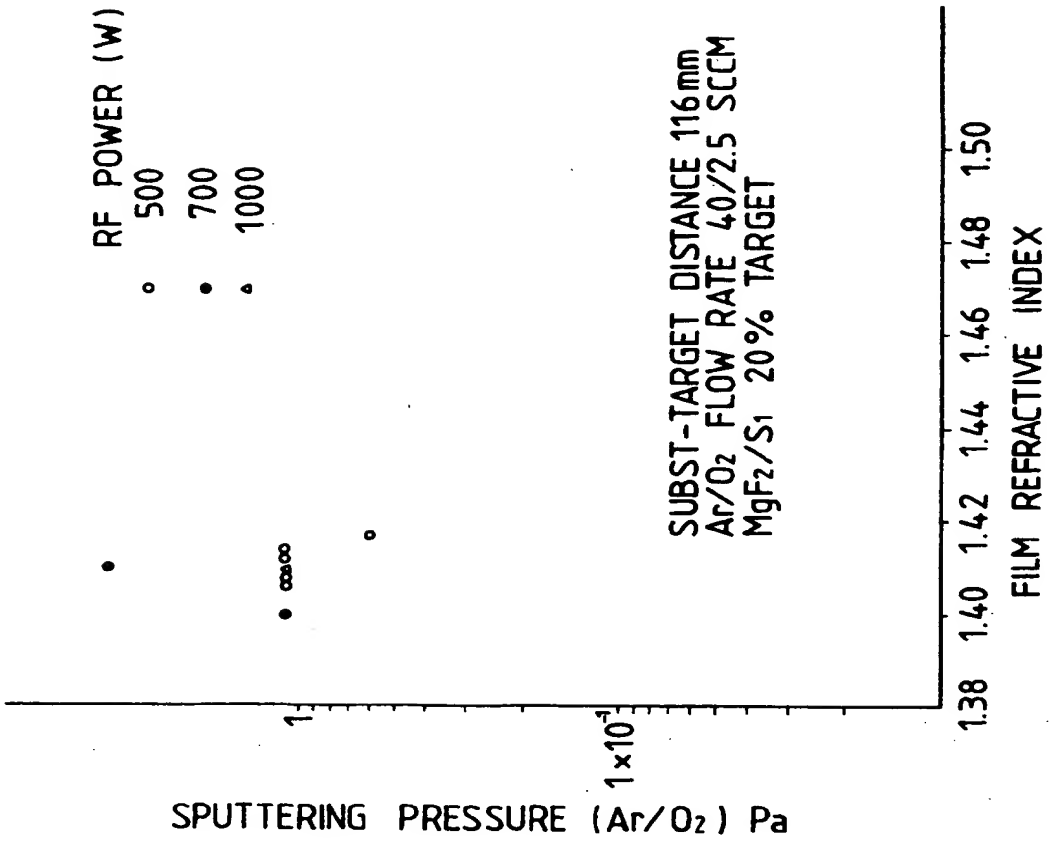
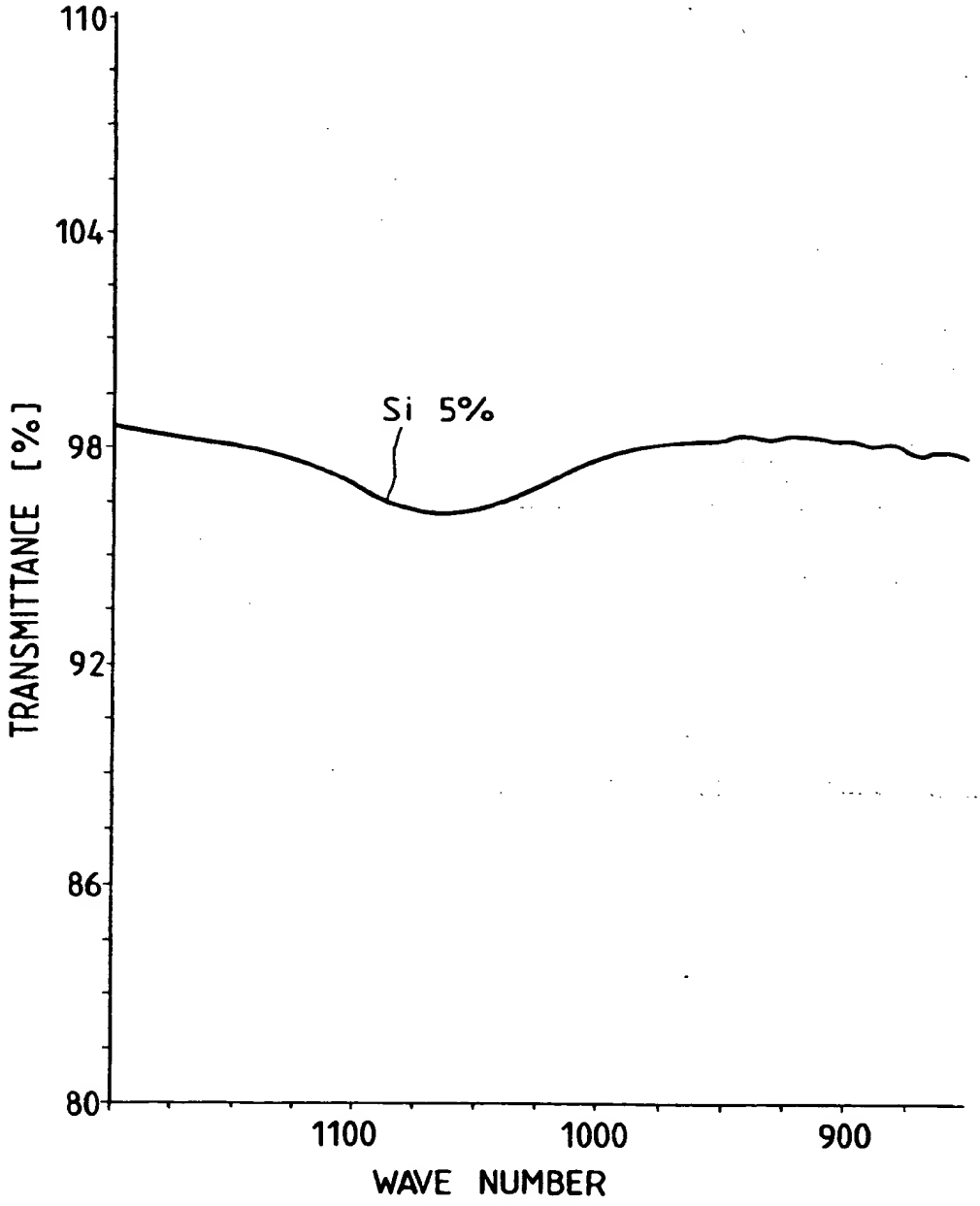

RF POWER (W)
500
700
1000
SUBST-TARGET DISTANCE 116mm
Ar/O2 FLOW RATE 40/2.5 SCCM
MgF2/Si 20% TARGET
1
1x10-1
SPUTTERING PRESSURE (Ar/O2) Pa
1.38
1.40
1.42
1.44
1.46
1.48
1.50
FILM REFRACTIVE INDEX

FIG. 17


110
104
98
92
86
80
TRANSMITTANCE [%]
Si 5%
1100
1000
900
WAVE NUMBER

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 30 5132

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
X	OYO BUTURI vol. 59, no. 7 , July 1990 , JP pages 953 - 958 OHTANI ET AL 'Optical Coatings for High Power Laser Produced by Mixed Films Method' * the whole document *	1	G02B1/10
A	---	2-7	
A	WISSENSCHAFTLICHE ZEITSCHRIFT DER TECHNISCHEN UNIVERSITAT DRESDEN vol. 39, no. 1 , 1990 , DRESDEN DDR pages 151 - 156 THIELSCH ET AL 'Strucktur und Eigenschaften dielektrischer Mischschichten für optische Anwendungen' * the whole document *	1,3	
D,A	---		
	JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY: PART A vol. A7, no. 3 , May 1989 , NEW YORK US pages 1248 - 1253 RUSSAK ET AL 'Reactive Magnetron Sputtered Zirconium Oxide and Zirconium Silicon Oxide Thin Films' * the whole document *	1,3,7,8	TECHNICAL FIELDS SEARCHED (Int.Cl.5) G02B
D,A	---		
	JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY: PART A vol. A4, no. 6 , November 1986 , NEW YORK US pages 2969 - 2974 FELDMAN ET AL 'Modifying Structure and Properties of Optical Films by Coevaporation' * the whole document *	1,3	

	-/--		

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	24 November 1993	Ward, S

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 30 5132

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
D,A	PATENT ABSTRACTS OF JAPAN vol. 15, no. 414 (M-1171)22 October 1991 & JP-A-03 173 638 (ASAHI GLASS) 26 July 1991 * abstract * ---	1,3	
D,A	PATENT ABSTRACTS OF JAPAN vol. 15, no. 396 (M-1166)8 October 1991 & JP-A-03 162 943 (ASHAI GLASS) 12 July 1991 * abstract * -----	1,4	
			TECHNICAL FIELDS SEARCHED (Int.Cl.5)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	24 November 1993	Ward, S

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L : document cited for other reasons

& : member of the same patent family, corresponding document

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